

AGRONOMIC RATES OF BIOSOLIDS FOR SOFT WHITE WINTER WHEAT PRODUCTION

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Introduction

Biosolids are stabilized solids derived from municipal wastewater treatment that meet Federal criteria for land application. They are an inexpensive source of nutrients and organic matter (Sullivan, 1998). Successful land application of biosolids has occurred in Oregon for the past 20 years and, with current economics, long distance transport to central Oregon is a viable option for large, western Oregon, wastewater treatment facilities. Biosolids application rates are based on supplying adequate N for the crop, without excessive nitrate losses via leaching. The rate of biosolids application that substitutes for normal N fertilization practices is known as the "agronomic rate".

Field trials with anaerobically-digested, dewatered biosolids in central Washington, showed that 26 to 31 percent of the applied biosolids N was recovered as available N (ammonium + nitrate-N) 9 to 12 months after application (Cogger et al., 1998). The lowest biosolids application rate in the study (approximately 300 lb N/acre) produced equivalent grain yields with higher grain protein than anhydrous ammonia (50 lb N/acre).

Previous biosolids research in Sherman County (Sullivan et al., 1998) showed that an application of about 230 lb biosolids N/acre (2.4 dry ton/acre) produced grain yield and plant N concentrations equivalent to those produced with application of 50 lb N/acre as anhydrous ammonia.

The present research continues our evaluation of agronomic rates of biosolids for soft-white wheat production in the 10–14 in. precipitation zone of eastern Oregon. To determine the agronomic rate, we compared plant-available soil N, grain yield, and N uptake for biosolids vs. anhydrous ammonia fertilization. We also collected soil and plant tissue samples to assess the effect of biosolids application on the supply of other plant-essential nutrients.

Materials and Methods

Site

Data was collected from one on-farm test site, located in the SW $\frac{1}{4}$, SW $\frac{1}{4}$ Section 16, T1N, R17E, 2 mi south of Wasco on Hwy 97 in Sherman County, Oregon. The soil has been mapped as a Walla Walla silt loam (> 60 in.). The cooperating grower (L.P. McClennan) performed routine tillage and crop management practices associated with a typical wheat-fallow rotation. The site had a winter wheat crop in 1996 (before our study) and in 1998 (completion of our study). Common soft-white wheat *Triticum aestivum* (Stephens/Madsen mix) was seeded in late September 1997.

Experimental Treatments and Design

Biosolids (anaerobically-digested and dewatered, 17 percent dry matter, 83 percent water) were supplied by the Unified Sewerage Agency (USA) of Washington County, Oregon. Biosolids trace-element concentrations met Federal requirements for land application.

Three biosolids rates (low, medium, and high) were applied using a rear-delivery manure spreader equipped with a hydraulic ram (Table 1). Biosolids treatments were

P residuals from tertiary treatment become part of the fall biosolids. In the spring, the biosolids contain only solids from primary and secondary wastewater treatment.

Table 1. Fertilizer application rates and timing. McClennan Farm, Sherman County, 1996-97.

Fertilizer applied [†]	Application date	Biosolids rate	Total nutrients applied [‡]		
			N	P	S
		dry ton/acre	lb/acre		
None	-	-	-	-	-
Anhydrous ammonia	9 June 97	-	60	-	-
BS low	16 Oct. 96	1.7	140	120	40
BS medium		3.4	290	230	70
BS high		5.1	430	350	100
BS low	25 Apr. 97	1.7	170	90	40
BS medium		3.4	340	180	70
BS high		5.1	510	270	100

[†]BS = Biosolids applied to standing stubble the fall after crop harvest (16 Oct. 1996), or in the spring prior to first fallow tillage (25 Apr. 1997).

[‡]Based on biosolids application rate and biosolids total N, P, and S analyses performed by AgriCheck Inc., Umatilla, OR.

applied in the fall after crop harvest (16 Oct. 1996) and in the spring before the first fallow tillage (25 Apr. 1997). The interval between biosolids application and the first fallow tillage was about six months for the fall application and about one month for the spring application. These application dates represent the most workable application times for biosolids in a wheat-fallow cropping system.

The composition of the biosolids varied somewhat from fall to spring (Table 1), because the wastewater treatment process changed seasonally. Biosolids produced in the fall are a combination of solids from primary, secondary, and tertiary wastewater treatment. Tertiary wastewater treatment, using alum (aluminum sulfate), removes additional P from the wastewater. The high-

The biosolids applications were compared to an anhydrous ammonia control (60 lb N/acre, applied 6 June 1997) and an unfertilized control. Biosolids and unfertilized plots measured 40 × 350 ft, and the anhydrous ammonia plots measured 60 × 350 ft (to accommodate the anhydrous ammonia applicator).

Soil Sampling

Soil samples were collected in 12 in. increments in the fall of the fallow year (3 Sept. 1997; 0–24 in depth), before rapid growth in the spring of the crop year (20 Mar. 1998, 0–60 in depth), and after grain harvest (30 July 1998, 0–60 in depth). The samples at the end of the fallow year (3 Sept. 1997; 0–24 in depth) were collected manually with a 0.75 in i.d. push tube (Arts

Manufacturing, American Falls, ID). The deep-soil samples (0–60 in) were collected with a hydraulic auger probe (Kauffman Mfg., Albany, OR) mounted on a small tractor. Soil samples were dried at 80 °F, ground, and sieved to pass through a 0.08 in sieve. We also collected surface-soil samples (0–6 in) on 20 Mar. 1998 for analysis of additional nutrients.

Plant Sampling

We collected 30 flag leaves from each plot for determination of leaf-nutrient concentrations at early flowering (23 May 1998, Feekes 10.5). Biomass (grain + straw) samples were hand-harvested from five, 1-m sections of row from each plot on 15 July 1998. We used the biomass samples to determine grain harvest index and to obtain straw samples for N analysis. Sample bundles were threshed to remove the grain with a small plot thresher. The straw exiting the thresher included the grain chaff.

At harvest, we measured grain yield from a 27-ft swath from the center of each plot. We collected a 2-lb sub-sample from each plot for determination of grain test weight and protein.

Results and Discussion

Biosolids application rate had a major impact on grain yield, crop nutrient concentrations, and soil nutrient concentrations. Biosolids application date (fall vs. spring) had only a small impact on these variables.

Available soil N

The slope of the regression line for each sampling date was used to estimate the increase in available soil N caused by

biosolids application (Fig. 1). Biosolids application increased available soil N (ammonium-N + nitrate-N) for the fall fallow sampling and the spring sampling. Postharvest soil samples showed that there was no significant increase in residual soil N from biosolids application.

For the fallow sampling, the slope of the regression line indicated that approximately 22 percent of the applied biosolids N was recovered in plant-available forms 4 to 10 months after application (Fig. 1a). Over 60 percent of this available soil N was recovered from the 0–12 in. depth.

For the spring sampling, approximately 30 percent of the biosolids N applied was in plant-available forms (Fig. 1b). Nearly all of the available N was in the nitrate form and was concentrated at the 12–24 in. depth (Fig. 2). The accumulation of nitrate at this depth suggested that little of the available N was lost from the root zone over the winter.

For postharvest sampling, the slope of the regression line indicated that biosolids application did not increase available soil N (Fig. 1c). The decline in soil N concentration between the spring of the crop year (Fig. 1b) and crop harvest largely reflects crop N uptake (Fig. 3d). Crop N uptake ranged from 43 to 66 percent of the available N present in the soil profile in early spring (Fig. 1b). This is a similar N uptake efficiency to that (45 to 70 percent) reported by others for soft white winter wheat (Fiez et al., 1995; Kjelgren, 1984). Additional soil N was also taken up by a heavy infestation of cheatgrass (*Bromus tectorum*). Cheatgrass biomass increased with biosolids application rate.

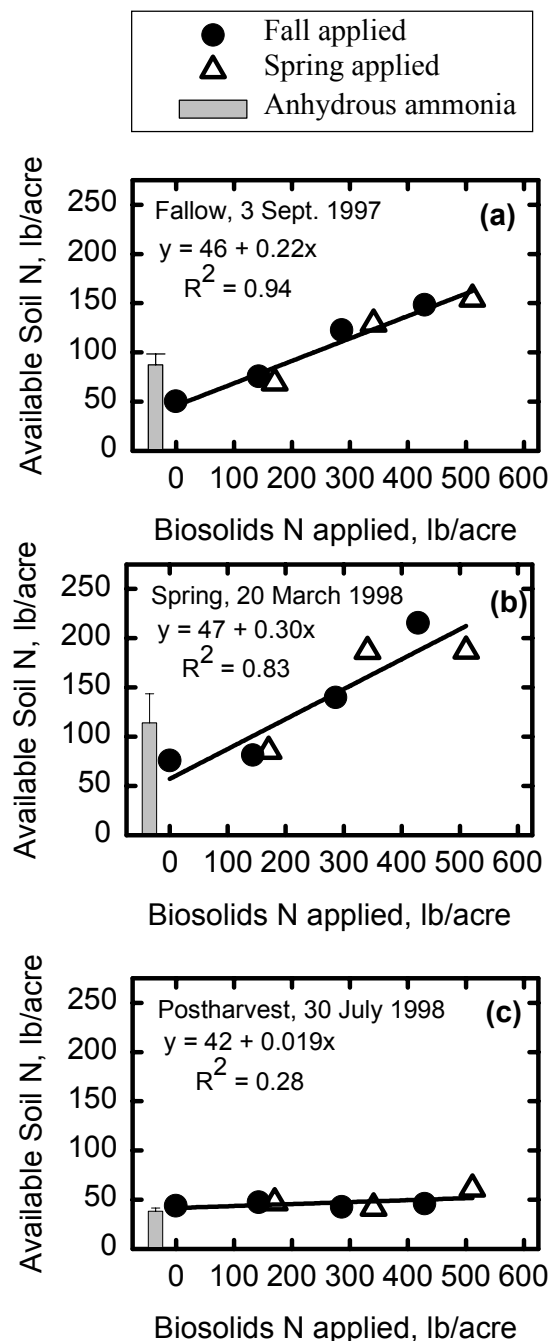


Figure 1. Anhydrous ammonia (AA; 60 lb N/acre) and biosolids effects on available soil N (ammonium-N + nitrate-N) in fallow (a); spring of the crop year (b); and postharvest (c). McClennan Farm, Sherman County, 1997–1998.

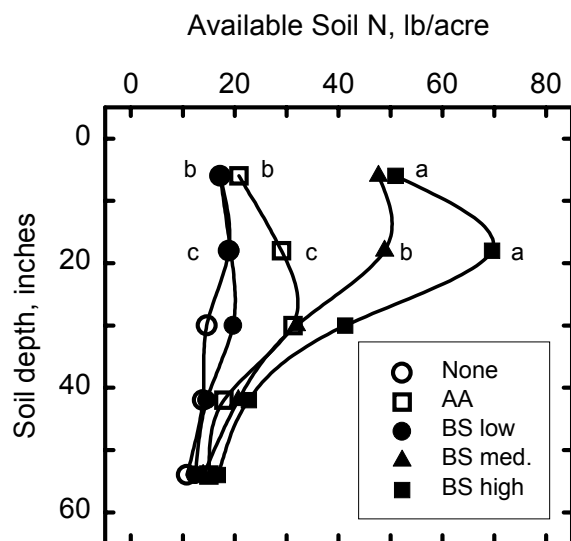


Figure 2. Anhydrous ammonia (AA; 60 lb N/acre) and biosolids effects on soil-profile distribution of available soil N (ammonium-N + nitrate-N), sampled in the spring of the crop year (20 Mar. 1998). For the 0–12 in. and 12–24 in. depths, symbols followed by a different letter were significantly different at $P = 0.05$. Values shown were the average for the fall and spring biosolids applications. McClennan Farm, Sherman County, 1998.

For this site, postharvest soil-N results were in general agreement with previous research in the 10 to 14 in. precipitation zone of eastern Oregon and Washington. Previous research in Sherman County showed that a biosolids application rate of 230 lb biosolids N/acre did not increase postharvest available soil N (Sullivan et al., 1998). Cogger et al. (1998) reported slightly higher postharvest nitrate levels with application of 300 lb biosolids N/acre than with 50 lb N/acre as anhydrous ammonia.

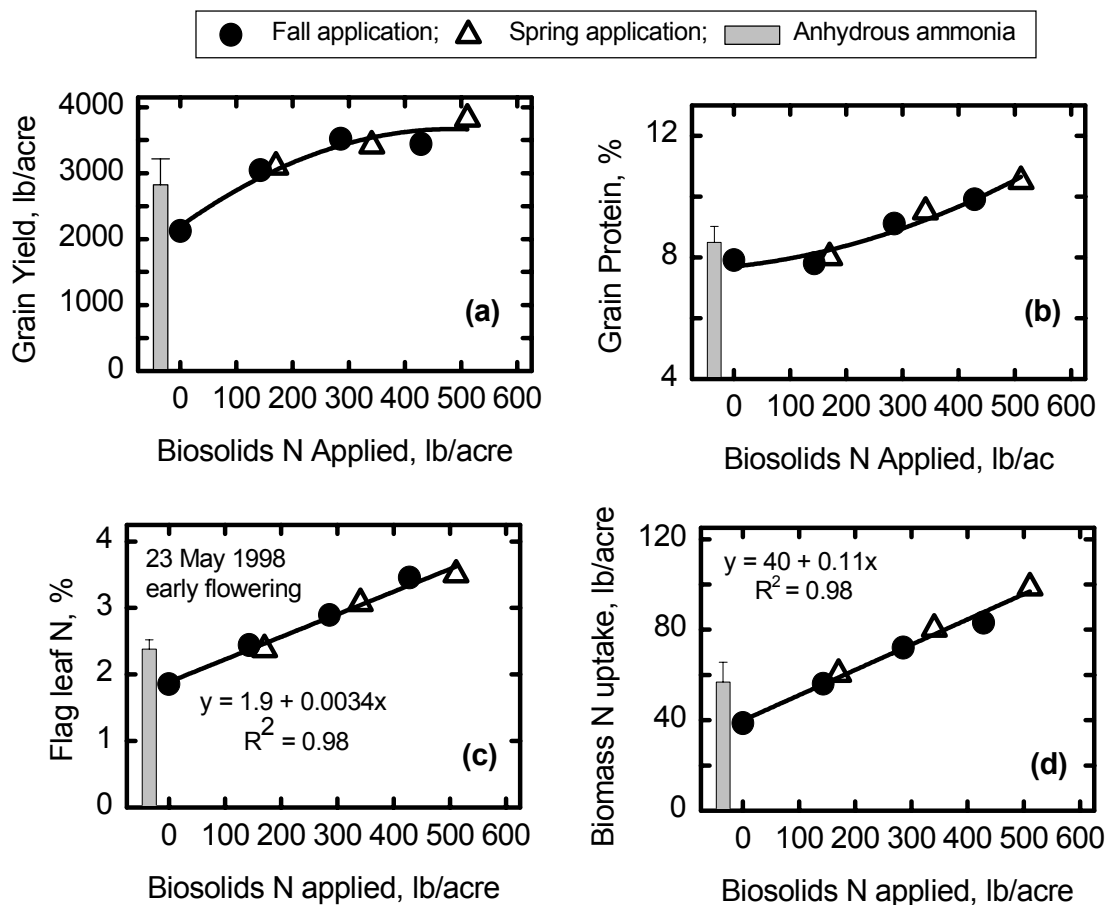


Figure 3. Anhydrous ammonia (AA; 60 lb N/acre) and biosolids effects on grain yield (a); grain protein (b); flag leaf N (c); and biomass (grain + straw) N uptake (d); of soft white winter wheat (Stephens/Madsen mix). McClennan Farm, Sherman County, 1998.

Grain yield and uptake of N

A number of agronomic measures were used to assess the effects of biosolids application rate on N availability, including grain yield, grain protein, flag-leaf N concentration, and biomass N uptake.

The low biosolids rate produced grain yield equivalent to that produced with the anhydrous ammonia. Yield-response to increasing biosolids rate was described by a quadratic regression model (Fig. 3a). The medium and high rates of biosolids produced significantly higher grain yields compared to anhydrous ammonia. High quality grain was produced with all rates of

biosolids. Grain test-weight was greater than 60.7 lb/bu for all biosolids application rates vs. 61.2 lb/bu for anhydrous ammonia.

Grain protein (Fig. 3b) was equivalent for the anhydrous ammonia (8.5 percent) and biosolids at the low rate (7.9 percent). Biosolids applied at the medium and high rates increased grain protein to 9.3 and 10.2 percent, respectively.

Flag-leaf N concentrations, another indicator of plant N status, were also similar for anhydrous ammonia and the low biosolids rate. Flag-leaf N concentrations

increased linearly with increasing biosolids rate (Fig. 3c).

Biomass N uptake (grain + straw) also increased linearly with biosolids rate. The low biosolids rate had equivalent N uptake to that produced with anhydrous ammonia (Fig. 3d). Increased grain protein (Fig. 3b) was responsible for most of the increase in biomass N uptake observed at higher biosolids rates. Straw N concentrations increased from 0.2 percent for anhydrous ammonia and the low biosolids rate to 0.3 percent for medium and high biosolids rates.

Based on crop response data for grain yield, grain protein, flag-leaf N concentration, and biomass N uptake, we concluded that the low rate of biosolids (140 to 170 lb biosolids N) supplied as much available N as 60 lb N/acre as anhydrous ammonia. Because of the timely and abundant rainfall during this cropping cycle, yield response to biosolids continued beyond the low biosolids rate (Fig. 3a). Maximum yield was produced with about

300 lb biosolids N applied, similar to results in previous studies (Sullivan et al., 1998; Cogger et al., 1998).

The detrimental effects of excess N at the high biosolids application rate, such as lodging, grain shrivel, very high grain protein (> 12 percent) and high residual nitrate-N were not apparent in the present study. Several factors were at work. First, the wheat varieties grown at this location, Stephens/Madsen, are moderately resistant to lodging, in contrast to the lodging-susceptible Eltan variety grown in previous studies (Cogger et al., 1998). Second, precipitation was above-average, with timely rainfall near the end of May. The abundant soil moisture reduced the risk of grain shrivel and high protein associated with luxuriant vegetative growth. Third, the cheatgrass proliferation at our site consumed all excess nitrate-N, whereas other sites had few weeds.

Availability of other nutrients

Biosolids application increased soil-test P, Cu, and Zn values (Table 2). It's unlikely that the grain-yield response

spring application. The greater P availability demonstrated with fall application was probably related to seasonal changes in biosolids production practices.

Table 2. Effect of biosolids and anhydrous ammonia application on soil test values [†]
Spring crop year sampling, 20 Mar. 1998. McClellan Farm, Sherman County, 1998.

Fertilizer applied [‡]	Application date	Soil test value (0–6 in. depth)				
		pH	Soluble salt conductivity mmhos/cm	P ----- ppm -----	Zn -----	Cu -----
None	-	5.9	0.18	49	0.9	2.1
Anhydrous ammonia	9 June 1997	5.9	0.17	52	0.9	2.0
BS low	16 Oct. 1996	5.8	0.19	61	1.2	2.4
BS medium		5.7	0.26	81	1.7	2.7
BS high		5.7	0.30	95	1.8	3.4
BS low	25 Apr. 1997	5.8	0.21	54	1.1	2.3
BS medium		5.6	0.31	59	1.4	2.4
BS high		5.4	0.49	69	1.7	2.6
PLSD (0.05)		0.13	0.14	8	0.3	0.4
CV (%)		2	33	8	14	12

[†]Soil testing performed by OSU Central Analytical Laboratory (Horneck, 1989). Phosphorus via Bray-1 extraction, zinc, and copper via DTPA extraction.

[‡] BS = Biosolids applied to standing stubble the fall after crop harvest (16 Oct. 1996), or in the spring prior to first fallow tillage (25 April 1997).

observed at this location was related to any other nutrient besides N because micronutrient levels were above levels reported for deficiencies (Lindsay and Norvell, 1978; Marx et al. 1996). These nutrients could provide a benefit at locations with higher-yield potential or for crops with higher-nutrient demand.

Phosphorus. Biosolids application increased the availability of soil-test P for the medium and high application rates (Table 2). The fall biosolids application increased available soil-test P more than the

The fall biosolids contained added P-rich residues from tertiary wastewater treatment, resulting in higher P application rates (Table 1). Also, the tertiary wastewater treatment residues present in the fall biosolids may contain P forms with higher availability. Soil-test P levels for all treatments were far above the level corresponding to P deficiency (20 ppm, Marx et al., 1996). The increased soil test P levels may provide a long-term benefit to crop production, but they can also lead to greater risk of off-site pollution of surface water. Biosolids application had limited effects on crop-P

uptake as indicated by flag-leaf and grain P concentrations (Table 3).

Flag-leaf S concentrations were higher with the fall-applied biosolids indicating a greater

Table 3. Effect of biosolids and anhydrous ammonia application on flag-leaf and grain nutrient concentrations. McClennan Farm, Sherman County, 1998.

Fertilizer applied [†]	Application date	Flag-leaf [‡]			Grain [§]		
		P	S	Zn	P	S	Zn
		---- % ----		ppm	---- % ----		ppm
None	-	0.23	0.15	10	0.33	0.10	18
Anhydrous ammonia	9 June 1997	0.24	0.18	11	0.32	0.09	15
BS low	16 Oct. 1996	0.26	0.24	13	0.32	0.10	17
BS medium		0.26	0.34	14	0.33	0.12	20
BS high		0.27	0.45	16	0.32	0.12	18
BS low	25 Apr. 1997	0.27	0.19	12	0.31	0.10	17
BS medium		0.27	0.26	15	0.31	0.11	17
BS low		0.26	0.30	17	0.31	0.13	18
PLSD (0.05)		NS	0.04	2	NS	0.01	NS
CV (%)		7	11	10	6	7	12

[†] BS = Biosolids applied to standing stubble the fall after crop harvest (16 Oct 1996) or the spring before first fallow tillage (25 Apr. 1997).

[‡] Flag-leaf sampled 23 May 1998, early flowering (Feekes 10.5).

[§] Sampled 24 July 1998, final harvest.

Sulfur. Biosolids increased extractable soil sulfate-S in samples taken in the fall of the fallow year. The increase in S availability averaged 15 percent of the biosolids S applied. Flag-leaf N:S ratios, an indicator of S deficiency, varied from 9:1 to 11:1, indicating that S was sufficient for all treatments (calculated from data in Table 3 and Fig. 3c). N:S ratios greater than 17:1 are associated with S deficiency (Rasmussen, 1996). Therefore, we conclude that S supply did not limit yield.

supply of available S (Table 3). The fall-applied biosolids contained alum (aluminum sulfate) residues from tertiary wastewater treatment, while the spring-applied biosolids did not.

Zinc. Biosolids application increased DTPA-extractable soil Zn (Table 2). Soil-test Zn values without biosolids were near reported deficiency levels (Marx et al., 1996; Lindsay and Norvell, 1978). Biosolids application increased flag-leaf Zn but did not increase grain Zn concentrations (Table 3).

Other nutrients. Biosolids application did not change extractable soil Ca, Mg, K, Na, B, or Fe. Small increases in DTPA-extractable soil Cu (+ 0.6 ppm) and soil Mn (+ 1.0 ppm) were measured for the high biosolids rate.

Soil pH and soluble salts. Overall, biosolids had little impact on soil pH and soluble salts (Table 2). There was no change in soil pH or soluble salt conductivity with the low rate of biosolids application. The medium and high rates of biosolids decreased soil pH and increased soluble salt conductivity. This reduction in soil pH, associated with soluble salts, was likely temporary. Soluble salts, such as the ammonium and nitrate present in the spring soil sample, reduced the measured soil pH. Available N was depleted by the end of the growing season (Fig. 1c). Other indicators of soil acidity, extractable soil Ca, and lime requirement (SMP buffer pH) remained the same for all treatments.

Soil testing results from this site confirmed earlier observations. Previous research in Sherman County demonstrated that biosolids provided plant-available P, S, and Zn with no change in soluble salts or soil pH (Sullivan et al., 1998).

Summary and Conclusions

Plant-available N supplied by biosolids was equal to 22 percent of the total N applied at seeding (4 to 10 months after application); it was 30 percent in the spring of the crop year. At harvest, no residual available N was measured with biosolids rates up to 510 lb total N/acre.

Biosolids applied at 140 to 170 lb biosolids N/acre produced grain yield and plant N concentrations equivalent to those produced with anhydrous ammonia at 60 lb N/acre. Maximum grain yield was produced with about 300 lb biosolids N applied,

similar to reported biosolids N rates for maximum yield in previous studies (Sullivan et al., 1998; Cogger et al., 1998). For grain production, fall- and spring-applied biosolids performed similarly. Increased biosolids application rates resulted in higher grain protein and flag-leaf N concentrations.

Biosolids application increased P, S, Cu, Mn, and Zn soil-test values. The grain-yield response to biosolids application was probably related only to the N supply. Biosolids applied at the low rate had no effect on soil pH or on soluble salt conductivity. Biosolids applied at the medium and high rates decreased the pH 0.2 to 0.5 units. This reduction in soil pH is probably temporary.

For the two sites where on-farm research has been conducted in Sherman County, the agronomic rate for soft-white wheat production is approximately 200 to 300 lb biosolids N/acre (2 to 3 dry ton/acre). This provides about 60 to 90 lb available N per acre for the first crop after application. The lower rate is recommended for high-tech manure spreaders that can accurately deliver 2 dry ton/acre (about 12 ton “as-is” biosolids/acre) and the higher rate for low-tech spreaders. Application rates above 300 lb biosolids N/acre (3 dry tons/acre) did not provide any agronomic benefits and may increase production risks. Greater risks of lodging, grain shrivel, cheatgrass proliferation, and high grain protein are associated with excessive application rates of biosolids.

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